Report on a Low Dissolved Oxygen Concentration Event in the Peace River, Spring 2005

Prepared by:

Theo Charette, M.Sc.
Water Quality Specialist
Tailwind Environmental Solutions

and

Evan Friesenhan, M.Eng., E.I.T.
River Engineer
Alberta Environment

June 2009

This document should be cited as:

Charette, T., and E. Friesenhan. 2009. Report on a low dissolved oxygen concentration event in the Peace River, March 2005. Prepared for Alberta Environment, Edmonton, AB.

EXECUTIVE SUMMARY

The Peace River in northeastern Alberta is normally a highly oxygenated river, averaging 11.4 mg/L dissolved oxygen (DO) near Fort Vermillion. However, routine monitoring at this site on March 15, 2005 revealed a DO concentration of 5.35 mg/L, which is near the acute Alberta Surface Water Quality Guideline for the Protection of Aquatic Life (Guidelines, 5 mg/L). Further monitoring downstream of Fort Vermillion (near Moose Island Crossing) on March 24 detected a (DO) concentration below the Guideline for the first time in recorded history. Because unapproved wastewater discharges were not reported, natural causes (i.e., Biochemical Oxygen Demand loading from surface runoff) were suspected. The goal of this report is to determine if the Peace River DO declines in March 2005 were caused by spring runoff.

The low DO was associated with a spring freshet peak that was tracked in the Peace River near the Town of Peace River (March 11), Peace Point (March 17) and Chennal des Quatres Fourches (March 20). The following results demonstrate that tributary loading, mainly from the Smoky River, caused this water peak in the Peace River:

- Grande Prairie minimum temperature was the highest on record in March 2005 and remained near the freezing point for about one and a half weeks;
- This relatively high minimum temperature caused an early spring runoff. Flow from the Smoky River was almost 8 times higher than the historical (i.e., 1915 to 2004) average in early March. At this time, discharge in the Smoky River was the highest on record and this spring pulse was about one month early. This pulse caused an ice jam on the Smoky River that released on March 11. Such an early spring pulse and iced jams were also noted in other tributaries in the area (e.g., North Heart River); and
- The peak in early March flows in the Peace River was detected only at stations downstream of the confluence with the Smoky River. The timing of this peak also corresponds to that of the release in the spring pulse from the Smoky River.

These results make a link between early and rapid spring runoff and Peace River peak water level and low DO. However, hard data to establish causality between tributary loading and Peace River DO decline is lacking. Unfortunately, there are no DO or BOD measurements from Smoky River water that was held back by the ice jam prior to release, which subsequently discharged into the Peace River at the time of the peak in Peace River water levels. Modelled peak-discharge BOD load from the Smoky River indicate that modelled Smoky River BOD load could not have caused a sag in Peace River. Albeit, the modelling was based on the assumption that the BOD concentration in the Smoky River follows the BOD/discharge relationship established from relatively deficient historical data. Also, there exists no DO data from the Peace River upstream of the Smoky River, which means that low DO water originating upstream of the Smoky River cannot be ruled out.

ACKNOWLEDGEMENTS

Hard work from John Willis, Scott Flett, Greg Poirier, and Salina Perry (AENV, Monitoring Branch), enabled prompt collection of data from the Peace River. We thank Carmen delaChevrotière for providing information on historical river discharge and Environment Canada for providing water quality information. Review comments were kindly provided by Preston McEachern, Alina Wolanski, and Chandra Mahabir (AENV, Northern Region, Edmonton).

TABLE OF CONTENTS

EXECUTIVE SUMMARY 1
ACKNOWLEDGEMENTS 2
LIST OF TABLES 4
LIST OF FIGURES 4

1.0 INTRODUCTION 5

2.0 METHODS 5

3.0 RESULTS AND DISCUSSION 7

3.1 Dissolved oxygen concentrations in the Peace River 7
3.2 Peace River flows and levels 8
3.3 Runoff and Tributary Loading 11

4.0 CONCLUSIONS AND RECOMMENDATIONS 17

5.0 REFERENCES 19

APPENDIX A: Dissolved oxygen concentrations in the Peace River at the Long Term River Network station near Fort Vermillion. 21

APPENDIX B: Dissolved oxygen concentrations in the Peace River at the ex-Alberta Environment Long Term River Network station near Dunvegan, 1984 to 1994. 27

APPENDIX C: Smoky River BOD and associated discharge. 29

LIST OF TABLES

Table 1: Peace River DO measurement events (March 15 to April 1, 2005).....7

Table 2: Summary of DO measurements taken from the Peace River during March 15 to April 1,2005. Stations are listed in order, from furthest upstream (Town of Peace River) to furthest downstream (Moose Island Crossing)..... 10

Table 3: Summary statistics for March DO measurements from the Peace River at Dunvegan and Fort Vermillion stations. 10

LIST OF FIGURES

Figure 1: Peace River basin in Alberta showing hydrometric and water quality stations on the Peace River. 9

Figure 2: DO concentrations in the Peace River at the Alberta Environment Long Term River Network station near Fort Vermillion, 1996 to 2005. Note that oxygen concentration measured in March 2005 is the lowest on record..... 10

Figure 3: Peace River flows during February and March 2005..... 11

Figure 4: Historical (1915-2005) flows in the Peace River near the Town of Peace River. Note that the March 11th flow reading, corresponding to the spring peak in the Peace River, was the highest on record for that date. 13

Figure 5: Water level peaks between Peace River (RPEAPEA), Peace Point (RPEAPOT) and Chennal des Quatres Fourches (RPEAQUAT..... 14

Figure 6: Historical (1943-2005) minimum temperatures at Grande Prairie. Note that the early March temperatures were the highest on record for that period. 16

Figure 7: Historical (1916-2005) flows in the Smoky River near Watino. Note that the early March flows were the highest on record for that period..... 17

Figure 8: BOD/Discharge relationship in the Smoky River. 18

1.0 INTRODUCTION

The Peace River is normally a highly oxygenated river near Fort Vermillion, averaging 11.4 mg/L dissolved oxygen (DO) from May 1988 to February 2005 (unpublished data). Routine long-term monitoring occurred on March 15, 2005, in the Peace River near Fort Vermillion at which time DO concentration was measured at 5.35 mg/L. This concentration was much lower than expected in the Peace River in March and it neared the acute Alberta Surface Water Quality Guideline for the Protection of Freshwater Aquatic Life (5.0 mg/L, AENV 1999).

Depletion of DO in aquatic environments under ice is generally caused by ice-cover blocking reaeration, inputs of oxygen-depleted waters under ice and oxidation of organic material in the system (Clescerl et al. 1999). Although these factors have long been recognized, limited data exists on DO conditions in ice-covered rivers in Alberta. It is clear, however, that under-ice DO is vital for the survival of cold-water biota. Concentrations below 6 mg/L can affect fish reproductive success and limits benthic invertebrate survival in Alberta rivers (Chambers et al. 2000).

Widespread DO sags in the Peace River have never been observed, indicating an unusual event. Because unapproved wastewater discharges to the Peace River were not reported during March 2005, natural causes (i.e., biochemical oxygen demand loading from surface runoff) were suspected. Indeed, the Peace River normally exhibits high turbidity during runoff events (Jang 1996). The goal of this report is to examine DO in the Peace River and to determine if the DO declines in March 2005 were caused by spring runoff. The primary hypothesis is that the sag in Peace River DO was caused by tributary loading of oxygen-depleted waters under ice.

2.0 METHODS

Local climate, discharge, and water quality data were examined to determine if there occurred a period of warm weather that caused a tributary discharge event that then caused a DO sag in the Peace River. The following approach was followed:

- Grande Prairie climate records were examined to determine if minimum temperatures reached the melting point for a sustained period of time;
- Hydrographs from stations along the Peace River were examined to determine if, and at what point along the Peace River, spring freshet occurred;
- The spring freshet peak was tracked along the Peace River to determine if its location coincided with low DO measurements;
- The Smoky River hydrograph, a tributary of the Peace River, was examined to determine if tributary discharge peaked at the time of the low DO event in the Peace River; and
- Biochemical oxygen demand (BOD) loading was calculated for the Smoky River to determine the effect of tributary loading on Peace River DO.

Water discharge and level data downstream of the Peace Canyon Dam and climate data for the City of Grande Prairie were obtained from the Water Survey of Canada website (www.wsc.ec.gc.ca/). Water quality data were obtained from Alberta Environment for the following stations:

- Peace River at:
    - Dunvegan (55°55'13", 118°36'20");
    - Town of Peace River (56°13'28", 117°17'20");
    - Tomkin's Landing (57°58'20", 117°08'46");
    - Fort Vermillion (58°23'14", 116°02'00");
    - Moose Island Ice Crossing (58°56'56", 111°42'24"); and

- Smoky River at Watino (55°42'57", 117°37'30").

The location of the March 2005 water level peak on the Peace River was inferred from the peak's calculated speed. The peak's speed was calculated as distance over time of travel for the maximum level of the March 2005 peak between the Town of Peace River (RPEAPEA), the gauge at Peace Point (RPEAPOT), and the gauge at Chennal de Quatre Fourches (RPEAQUAT).

Flows from the Smoky River, a major tributary to the Peace River, during the low DO event were examined as an indicator of runoff conditions. The Water Survey of Canada measured daily flows in the Smoky River from 1915 to 2005. Smoky River flow data used coincided with the water level peak in the nearby station of Peace River near the Town of Peace River. Average flows were calculated from March 5 (i.e., first date of peak in water level) to March 19 (i.e., end of peak).

Effect of Smoky River BOD loading on Peace River water quality was estimated using the following conservation of mass concentration equation that assumes instantaneous mixing of Smoky River water with Peace River water:

$[DO]'_{PR} = (([DO]_{PR} \times Q_{PR})+([DO]_{SR} \times Q_{SR})) \times (Q_{PR}+Q_{SR})^{-1}$, where

$[DO]'_{PR}$ = Calculated dissolved oxygen concentration in the Peace River on March 11th
$[DO]_{PR}$ = Pre-2005 average dissolved oxygen concentration in the Peace River during March
$[DO]_{SR}$ = Calculated dissolved oxygen concentration in the Smoky River during peak discharge (March 11th)
Q_{PR} = Discharge in the Peace River above the Smoky River (at Alces) on March 11th
Q_{SR} = Discharge in the Smoky River on March 11th

$[DO]_{SR}$ was calculated using a mass-balance approach. The initial DO concentration in the Smoky was calculated as the average March DO concentration. Peak discharge BOD was estimated using the regression equation calculated between historical BOD and discharge in the Smoky River. The regression was calculated while setting the intercept to 0.

Data plotting and statistics were conducted with Microsoft Office 2004.

3.0 RESULTS AND DISCUSSION

March 2005 water discharge data were available for 5 stations on the Peace River downstream of the Peace Canyon Dam: at Hudson Hope (RPEAHUD), upstream of Pine River (RPEAPINE), at Taylor (RPEATAY), at Alces (RPEAALCE), at Peace River (RPEAPEA), and at Peace Point (RPEAPOT) (Fig. 1). March 2005 water level data were available for 4 stations on the Peace River downstream of the Peace Canyon Dam: at Elk Island Park (RPEAELK), upstream of Smoky River (RPEASMOK), RPEAPEA, PREAPOT, and at Chennal des Quatres Fourches (RPEAQUAT).

Water was sampled from the Peace River near Fort Vermillion on March 15th as part of routine monthly monitoring. In response to a detection of low DO at the Fort Vermillion station, additional sampling of DO occurred in the Peace River in March 2005, upstream of the Town of Peace River, at Tomkin's Landing Crossing, near Fort Vermillion, and Moose Island Ice Crossing (Table 1). Unfortunately, at the time, DO had not been monitored in the Peace River upstream of the confluence with the Smoky River.

Table 1: Peace River DO measurement events (March 15 to April 1, 2005).

Date	Location	Time
March 15	Fort Vermillion	14:45
March 21	u/s Peace R town	13:50
March 22	Fort Vermillion	11:45
March 22	Tomkin's Landing Crossing	15:35
March 24	Moose Island Crossing	18:00
March 29	Moose Island Crossing	18:00
April 1	Moose Island Crossing	NA- Ice conditions unsafe

3.1 Dissolved oxygen concentrations in the Peace River

Oxygen at the Alberta Environment Long Term River Network site (near Fort Vermillion) follows a seasonal pattern, oscillating between minimum concentrations in mid-summer to peak concentrations in mid-winter (Fig. 2). Therefore, DO is normally at near peak during the month of March, with average concentrations of 12.4 mg/L and a minimum pre-2005 March concentration of 11.4 mg/L (Table 3). Prior to March

2005, the lowest recorded DO in the Peace River near Fort Vermillion was 7.47 mg/L on July 15, 2004.

DO near Fort Vermillion was the lowest on record (i.e., 5.35 mg/L) on March 15th, 2005. Seven days later, on March 22, DO was higher (i.e., 9.1 mg/L) but concentrations were lower than the long-term average for March near Fort Vermillion (i.e., 12.4 mg/L). At this time, DO concentration near the Town of Peace River and at Tomkin's Landing were normal (13.2 and 11 mg/L, respectively). At Moose Island Crossing, low DO (i.e., 4.5 mg/L) was detected on March 24, but was normal (i.e., 10.5 mg/L) 5 days later.

3.2 Peace River flows and levels

An examination of flows at stations from Hudson Hope to Peace Point reveals that flows in early March peaked at the Town of Peace River station and downstream, indicating an increased load between the Alces River and the Town of Peace River (Fig. 3). The dip in flows upstream of the Town reflects lower discharge from the Peace Canyon dam in response to an ice jam in the Smoky River (AENV 2005). Due to its long period of record (i.e., 1916-2005), flows from the site near the Town of Peace River were examined to compare 2005 and pre-2005 hydrographs. Discharge in the Peace River near the Town of Peace River was fairly close to median during most of 2005 (Fig. 4). However, the 2005 hydrograph was shifted so that winter and spring discharges were relatively higher and summer discharge was lower than the median. Flows in early March 2005 were highest on record for the month of March.

The timing of low DO measurements in the Peace River corresponds to that of the Peace River water level peak. Water levels rose from 1 to 1.5 meters in the Peace River in relation to a water level peak that occurred in early March 2005 (Fig. 5). Travel time of this water level peak between the RPEAPEA and RPEAPOT gauges was roughly 6 days, which is equivalent to 125 km/day based on the 740 km river distance between the two gauges. Based on this travel distance, and a distance of 433 km between RPEAPEA and Fort Vermillion, the water level peak is predicted to have passed by Fort Vermillion on March 15, corresponding to the low DO measurement. This peak was then observed passing by RPEAPOT on March 17. Travel time between the RPEAPOT and RPEAQUAT was roughly 2.5 days, which is equivalent to approximately 36 km/day. Slower travel time is not surprising since this stretch of the river is much more sinuous. This travel time places the peak at Moose Island Crossing on March 19 to 20. The low DO in the Peace River at Moose Island Crossing was measured on March 24, which was on the recession limb of the runoff hydrograph. Nine days after the water level peaked at RPEAQUAT (March 29), DO concentrations were back to normal levels. In general, the low DO event coincided with a peak in Peace River water levels that corresponds to a spike in water levels originating downstream of the Alces River. Continuous DO data does not exist, thus determining the exact duration of low DO exposure along the Peace River is impossible. However,

both the water level peak and DO measurements indicate that below-average DO persisted for at least 5 to 7 days, depending on location, on the Peace River.

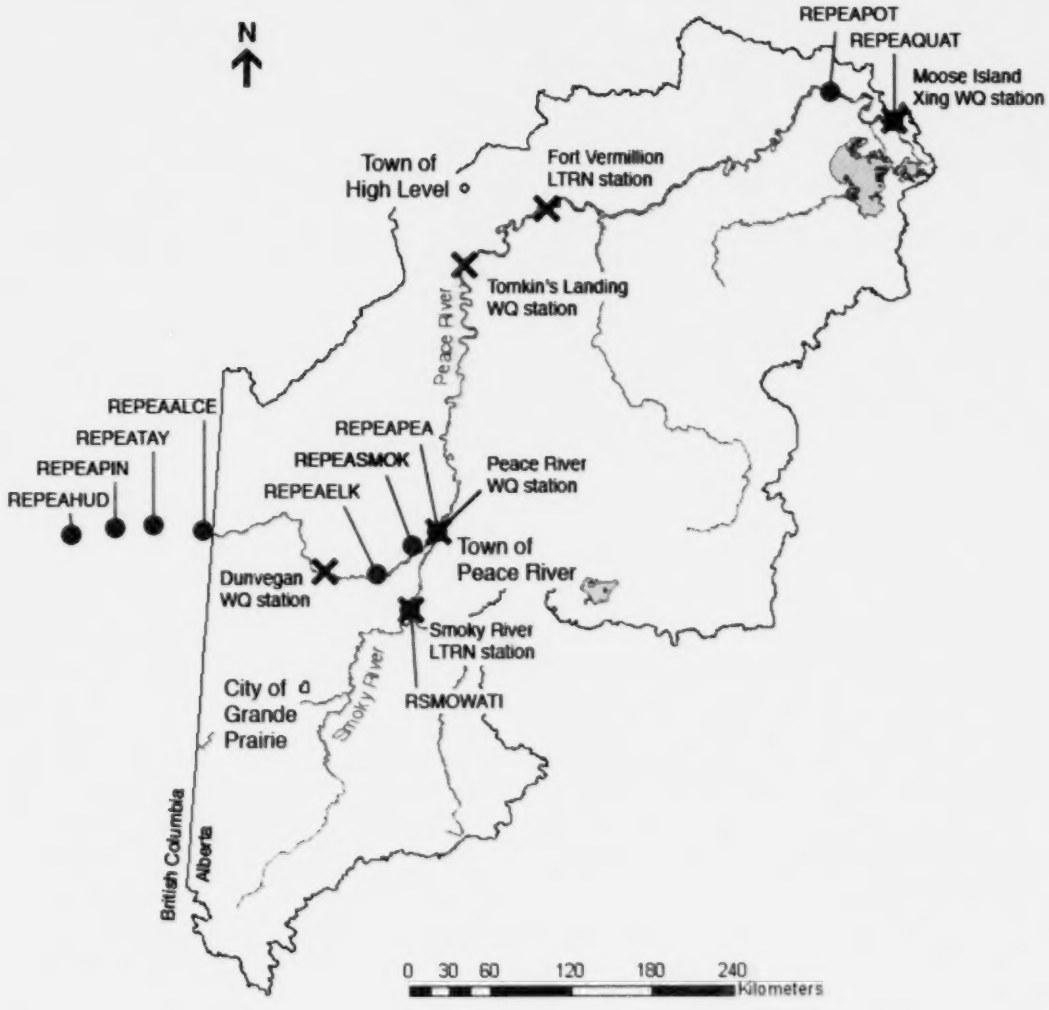


Figure 1: Peace River basin in Alberta showing hydrometric (●) and water quality (**X**) stations on the Peace River.

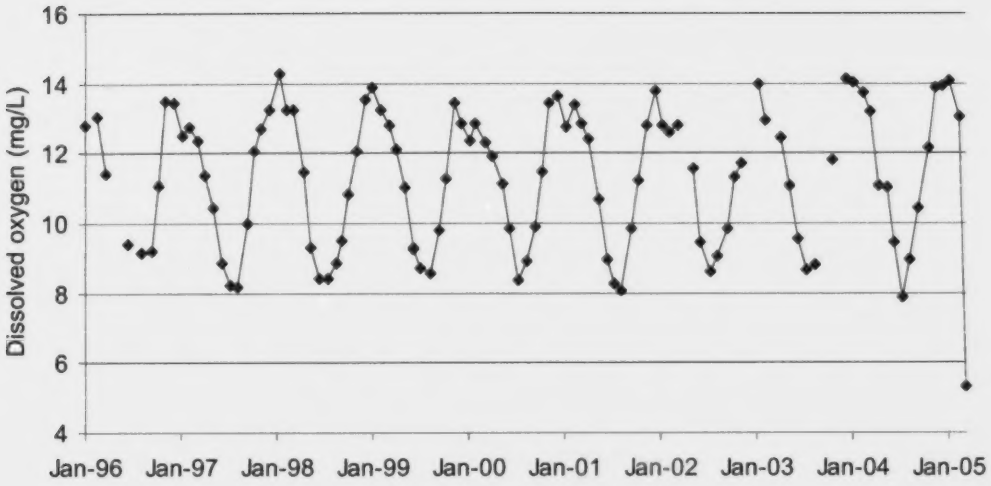


Figure 2: DO concentrations in the Peace River at the Alberta Environment Long Term River Network station near Fort Vermillion, 1996 to 2005. Note that oxygen concentration measured in March 2005 is the lowest on record.

Table 2: Summary of DO measurements taken from the Peace River during March 15 to April 1,2005. Stations are listed in order, from furthest upstream (Town of Peace River) to furthest downstream (Moose Island Crossing).

Date	Town of Peace River	Tomkin's Landing Crossing	Fort Vermillion	Moose Island Crossing
March 15			5.35	
March 21	13.25			
March 22		11.0	9.1	
March 24				4.5
March 29				10.5
April 1				NA- Ice conditions unsafe

Table 3: Summary statistics for March DO measurements from the Peace River at Dunvegan and Fort Vermillion stations.

Station	Period of record	N	Mean	Minimum	Maximum	Standard deviation	95% CI
Dunvegan	1958-1994	21	13.2	12.0	14.8	0.73	0.30
Fort Vermillion	1988-2005	16	12.3	5.4	13.3	1.92	0.94

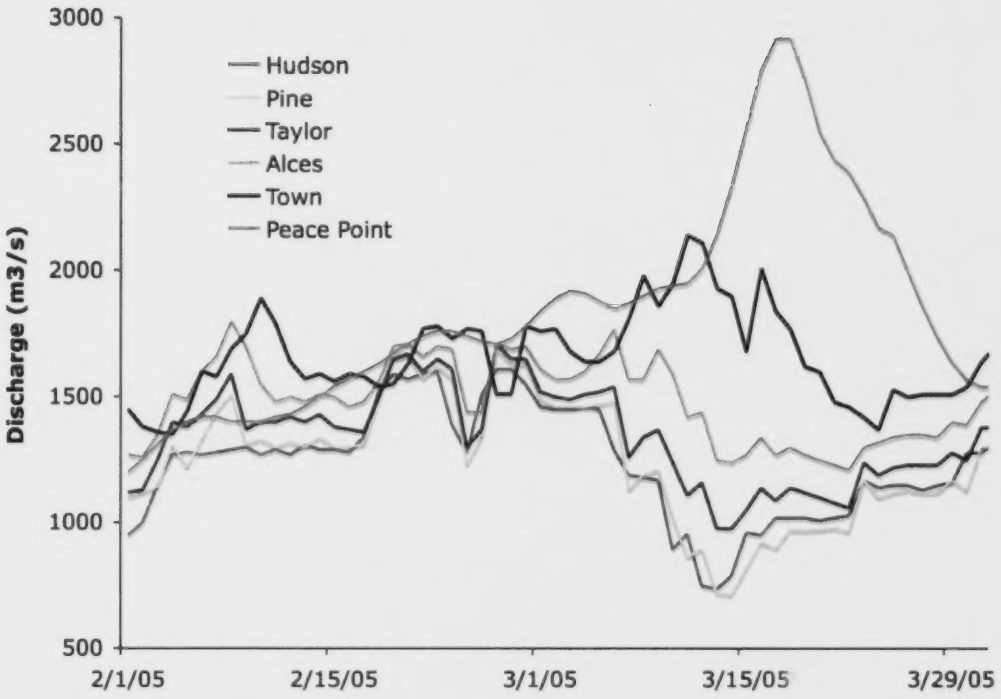


Figure 3: Peace River flows during February and March 2005.

3.3 Runoff and Tributary Loading

Unseasonably warm temperatures during early March caused early spring runoff in the Peace River area. Minimum temperatures, at the time, had reached freezing or above-freezing values for about one and a half weeks (Fig. 6). Pre-2005 average discharge in the Smoky River for the March 5 to March 19 period was 44.9 cubic meters per second (cms). During 2005, the average discharge over the same period was 337.9 cms, which is nearly 8 times greater than the pre-2005 average. The second-highest discharge occurred in 1992 and averaged 190 cms. Discharge in the Smoky River was the highest on record in March 2005 and this spring pulse was about one month early (Fig. 6). This pulse caused an ice jam on the Smoky River that released on March 11. This early spring pulse and iced jams were also noted in other tributaries in the area (e.g., North Heart River, AENV 2005).

Water quality samples were taken from the Smoky River at Watino on March 16, 2005, which corresponds to the downward side of the discharge peak (Fig. 7). On this date, oxygen concentration was average and BOD concentration was not particularly high in the Smoky (12.6 and 3.6 mg/L, respectively). Even though BOD concentration was

relatively low compared to other Alberta rivers, it was the highest on record for the Smoky, which historically exhibits low BOD (BOD_{mean} = 1.22 mg/L ± 0.96 SD).

There is a statistically significant relationship between BOD and discharge in the Smoky River (Fig. 8, $P < 0.005$, $R^2 = 0.64$). Peak daily flow in the Smoky River occurred on March 11 when it was recorded at 524 m^3/s. Using [BOD] = 0.0104 Q (Fig. 8) and an initial DO concentration of 11.2 mg/L, the calculated BOD and DO concentrations in the Smoky River on March 11 are 5.5 mg/L and 5.7 mg/L, respectively. Assuming instantaneous mixing and an initial $[DO]_{PR}$ of 12.4 mg/L and a Q_{PR} of 1590 m^3/s (discharge near Alces on March 10), a loading of 5.7 mg/L $[DO]_{SR}$ would have caused a decrease in $[DO]_{PR}$ to 10.6 mg/L. Using a Q_{PR} of 1240 m^3/s (minimum discharge near Alces, which occurred on March 14), causes a $[DO]'_{Peace}$ of 10.4 mg/L. Thus, according to the above calculations, Smoky River tributary loading of 5.5 mg/L BOD alone could not have caused the sag in DO in the Peace River. To drop $[DO]_{Peace}$ to 5 mg/L would require one or a combination of the following scenarios:

- Higher than expected BOD loading from the Smoky River; and/or
- Lower than normal initial DO in the Peace River.

These scenarios could also be exacerbated by reduced Peace River flows that diminished the dilution capacity of the Peace River.

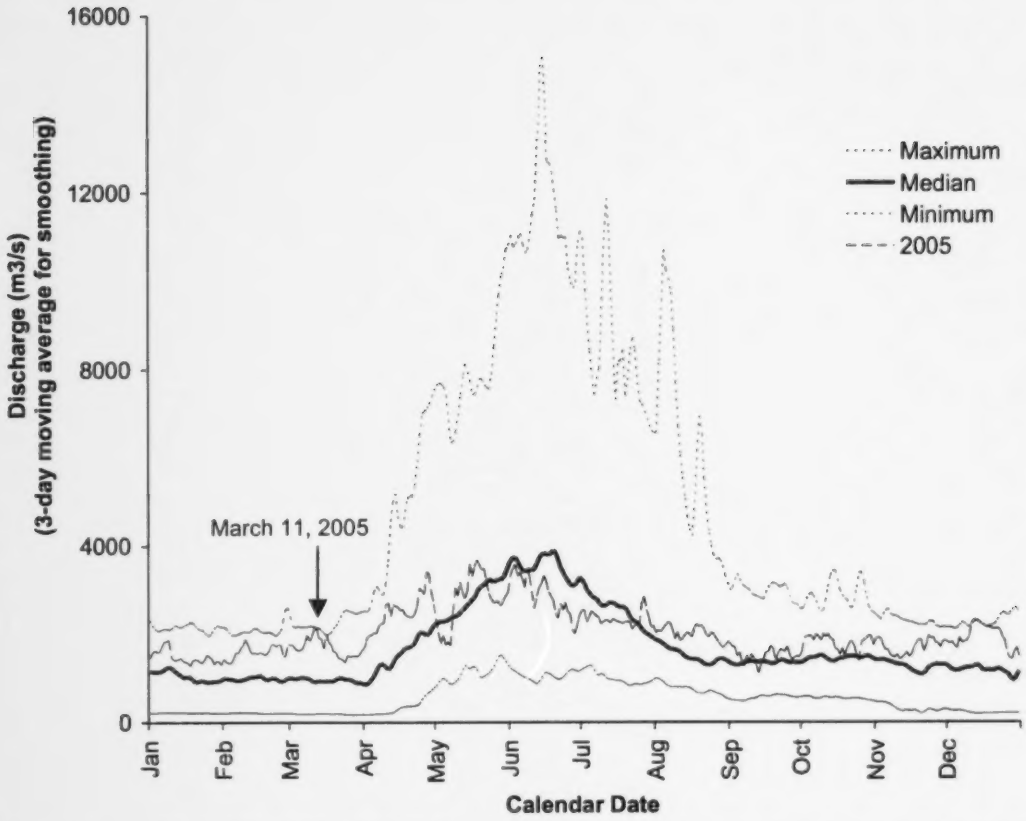


Figure 4: Historical (1915-2005) flows in the Peace River near the Town of Peace River. Note that the March 11th flow reading, corresponding to the spring peak in the Peace River, was the highest on record for that date.

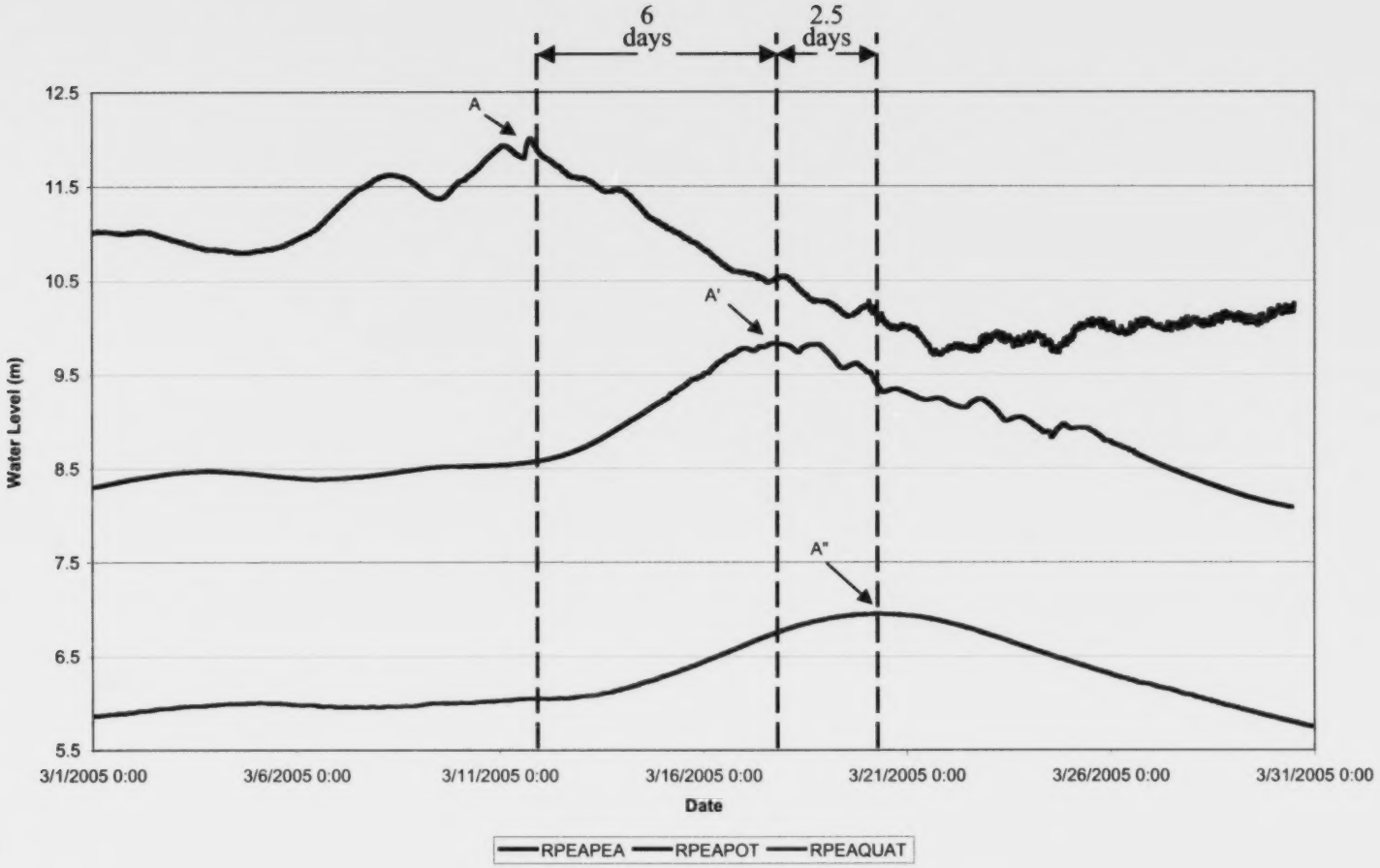


Figure 5: Water level peaks between Peace River (RPEAPEA), Peace Point (RPEAPOT) and Chennal des Quatres Fourches (RPEAQUAT

Hard data to establish the cause of Peace River DO decline is lacking. The Smoky River BOD estimation is based on a relationship derived from historical data. However, such an event as that of March of 2005 has never been recorded, and ample evidence exists that would qualify it as an unusual event. The historical range in BOD concentrations recorded in the Smoky River is quite limited and the data displays heteroscedasticity (i.e., variance of the dependent variable varies across the data) (Fig. 8). Although models are often built on such data, its applicability could be questioned. It is quite possible that the March 11th water, held back by an ice jam on the Smoky River, was abnormally high in BOD. Even under such a scenario, it is unlikely that Peace River DO could have sagged from 12.4 to 5 mg/L purely due to Smoky River influence. The Peace River's dilution potential is high since the Smoky River, at the time, only contributed a third to a quarter of the total Peace River discharge near the Town of Peace River. Historical DO concentrations at the Dunvegan station, which is the station upstream of the Smoky River with the most data, remained within 12 to 14.8 mg/L in March (1958-1994). Since then, however, DO upstream of the Smoky River has not been monitored up to 2005. In 2006, the Province of British Columbia and Environment Canada began year-round semi-monthly DO monitoring at the Alces station (EC 2009) and Alberta Environment began daily winter DO monitoring at Shaftsberry Crossing (upstream of the Town of Peace River). DO at Shaftsberry Crossing during March of 2006, 2007, and 2008 did not go below 12 mg/L (AENV, unpublished data). At Alces, however, Environment Canada reports a DO concentration of 7.5 and 9 mg/L on March 11, 2007 and February 27, 2008, respectively. Unfortunately, these data cannot be corroborated with that at Shaftsberry Ferry since the datasondes were not operational on these dates. Environment Canada also reports very low DO (5-6 mg/L) during mid-summer 2008 near Alces River. Thus, there is evidence that DO upstream of the Smoky River can drop below 12 mg/L on occasion.

Although indirect evidence points to Smoky River loading being at least partly responsible for the Peace River DO sag, the influence of upstream DO conditions cannot be ruled out.

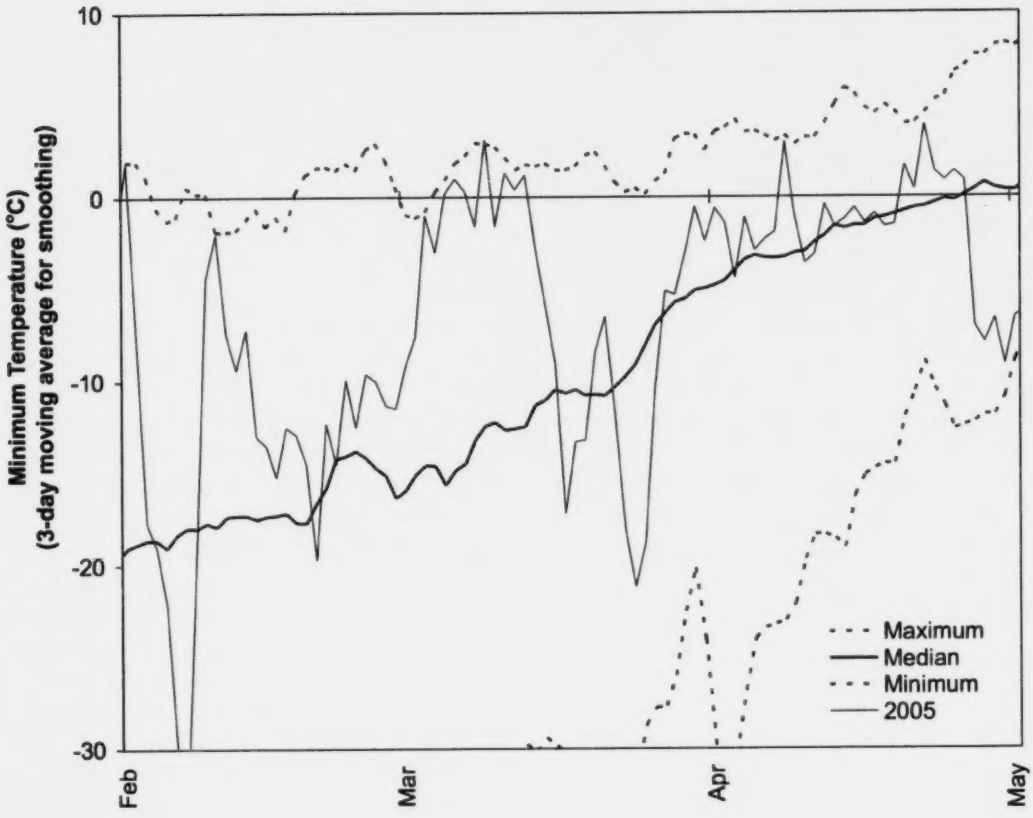


Figure 6: Historical (1943-2005) minimum temperatures at Grande Prairie. Note that the early March temperatures were the highest on record for that period.

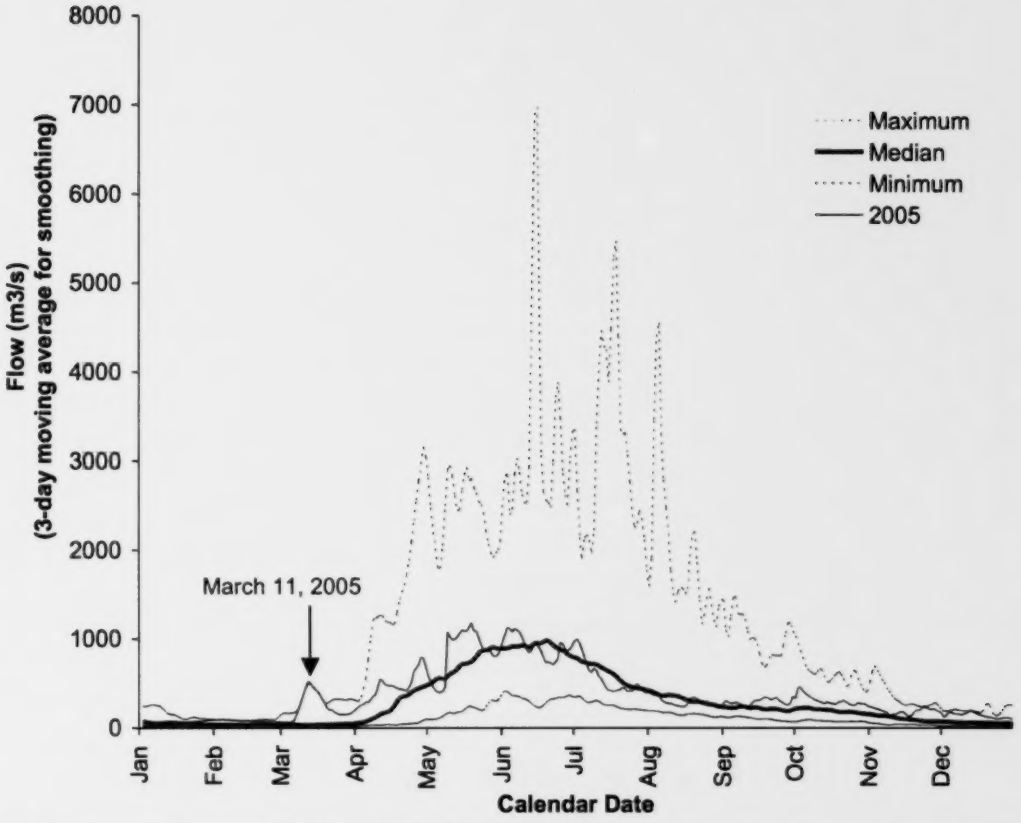


Figure 7: Historical (1916-2005) flows in the Smoky River near Watino. Note that the early March flows were the highest on record for that period.

4.0 CONCLUSIONS AND RECOMMENDATIONS

In summary, low (i.e., 4.5 to 5.3 mg/L) DO concentrations in the Peace River were measured in mid-March 2005. This low DO was associated with a spring freshet peak that was tracked along the Peace River. The following results demonstrate that tributary loading, mainly from the Smoky River, caused this water peak in the Peace River:

- Minimum temperature at the time of the event was the highest on record and remained near the melting point for about one and a half weeks;
- This relatively high minimum temperature caused an early spring runoff that caused record flows in the Smoky River for the month of March; and
- This pulse in Smoky River load caused water levels to peak in the Peace River at stations downstream of the confluence with the Smoky River.

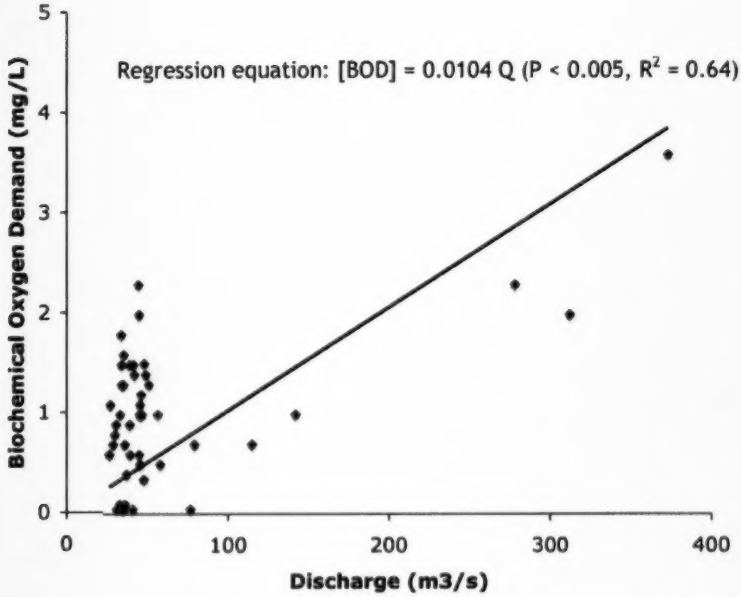


Figure 8: BOD/Discharge relationship in the Smoky River.

These results make a link between early and rapid spring runoff and Peace River peak water level and low DO. However, hard data to establish causality between tributary loading and Peace River DO decline is lacking. Unfortunately, there are no DO or BOD measurements from Smoky River water that was held back by the ice jam prior to release, which subsequently discharged into the Peace River at the time of the peak in Peace River water levels. Conservation of mass calculations indicate that modelled peak-discharge BOD load from the Smoky River could not have caused a sag in Peace River. Albeit, due to limited data, this modelling was based on the assumption that the BOD concentration in the Smoky River follows the BOD/discharge relationship established from relatively deficient historical data. Also, there exists no DO data from the Peace River upstream of the Smoky River during 2005, which means that we cannot rule out low DO water originating upstream of the Smoky River.

Further investigation is highly recommended due to the implications of the event and the hypotheses. Under ice DO is highly important for aquatic organisms and population and reproductive effects are known in northern rivers at 6 mg/L (Chambers et al. 2000). Also, accepted climate change scenarios for Alberta predict earlier spring thaw and increased extreme events (Sauchyn 2006). If abnormal and early spring discharge is found to cause the low DO event in the Peace River, the implications for aquatic ecosystems in northern rivers would be highly important. We recommend the deployment of datasondes during ice-on conditions in the Smoky River and in the Peace River at Fort Vermillion and upstream of the Smoky River confluence. The Provincial-Federal Water Quality Monitoring Program reports very low

DO upstream of the Alces River during 2008. These data should be examined and validation should be confirmed. These results support further monitoring of Peace River DO, especially if the data are correct. We also recommend additional BOD measurement in the Smoky River, particularly during high spring runoff events. This data could be used to strengthen the BOD/Discharge relationship. Lastly, we recommend the development of a water quality model for the entire Peace River, which would include point and non-point sources and their predicted effects on the Peace River. This model would be calibrated with increased monitoring data described above and could be used to run scenarios based on local and provincial concerns. Such a model would be highly useful to support the investigations of the upcoming Water Planning and Advisory Council.

5.0 REFERENCES

Friesenhan, E. 2005. Peace River ice observations 2004 - 2005. Report prepared for Alberta Environment. 217 pp.

Alberta Environment (AENV). 1999. Surface water quality guidelines for use in Alberta. Alberta Environment, Environmental Sciences Division. 20 pp.

Chambers, P.A., S. Brown, J.M. Culp, R.B. Lowell, and A. Pietroniro. 2000. Dissolved oxygen decline in ice-covered rivers of northern Alberta and its effects on aquatic biota. Journal of Aquatic Ecosystem Stress and Recovery 8: 27-38.

Clescerl, L.S., Greenberg, A.E., and Eaton, A.D. (eds.). 1999. Standard Methods for the Examination of Water and Wastewater, American Public Health Association, Washington. 1325 p.

Environment Canada (EC) 2009. Pacific and Yukon Water Quality Monitoring Program Website. http://waterquality.ec.gc.ca/.

Jang, L. 1996. State of the water quality of the Peace River above Alces River, 1984 - 1995. Water Quality Section, Ministry of Environment, Lands, and Parks, Victoria, British Columbia. 59 p.

Sauchyn, D., A. Pietroniro, and M. Demuth. 2006. Upland Watershed Management and Global Change - Canada's Rocky Mountains and Western Plains. Proceedings, Fifth Biennial Rosenberg Forum on Water Policy, September 6-11, 2006, Banff, Alberta.

APPENDIX A: Dissolved oxygen concentrations in the Peace River at the Long Term River Network station near Fort Vermillion.

Date	Dissolved oxygen (mg/L)
5/11/88	10.3
6/21/88	8.6
7/19/88	8.1
8/23/88	8.8
9/29/88	10
12/13/88	13.1
3/2/89	12.9
5/31/89	10.1
6/21/89	9.03
7/19/89	8.4
8/29/89	8.3
10/4/89	11.26
10/31/89	11.71
12/7/89	13.3
1/23/90	13.3
2/28/90	12.8
3/28/90	11.82
4/30/90	11.74
6/4/90	8.37
6/19/90	7.48
7/24/90	8.6
8/29/90	9.1
9/18/90	9.71
11/7/90	12.55
12/13/90	14.2
1/16/91	13.3
2/20/91	12.58
3/18/91	12.2
3/18/91	12.2
5/8/91	10.33
7/16/91	8.01
8/13/91	7.82
9/26/91	9.83
12/17/91	13.8
1/21/92	13.5
2/26/92	13.4
5/4/92	10.36
6/23/92	8.97
7/21/92	8.98
8/20/92	8.29
9/29/92	10.81
10/21/92	12.65
12/9/92	13.7
1/13/93	13.46
2/9/93	12.34
3/23/93	12.97
5/5/93	11.1

APPENDIX A (ctn'd): Dissolved oxygen concentrations in the Peace River at the Long Term River Network station near Fort Vermillion.

Date	Dissolved oxygen (mg/L)
6/22/93	8.9
9/8/93	9.04
10/14/93	11.3
11/15/93	12.29
1/14/94	13.98
3/21/94	12.72
4/19/94	10.2
5/25/94	9.53
6/20/94	8.58
7/26/94	7.58
10/3/94	10.4
11/1/94	11.83
11/23/94	13.86
1/10/95	13.76
2/8/95	13.27
3/14/95	13.34
5/16/95	8.67
6/7/95	9.02
7/10/95	8.27
12/13/95	12.81
1/10/96	12.81
2/7/96	12.3
2/27/96	13.06
3/27/96	11.44
4/24/96	9.2
5/14/96	10.66
6/19/96	9.4
7/17/96	9.44
8/14/96	9.18
9/18/96	9.19
10/17/96	11.09
11/14/96	13.5
12/12/96	13.43
1/16/97	12.51
2/13/97	12.73
3/13/97	12.36
4/9/97	11.39
5/14/97	10.44
6/17/97	8.88
7/15/97	8.23
8/13/97	8.16
9/17/97	10.02
10/15/97	12.08
11/13/97	12.69
12/17/97	13.23
1/21/98	14.27
2/19/98	13.23

APPENDIX A (ctn'd): Dissolved oxygen concentrations in the Peace River at the Long Term River Network station near Fort Vermillion.

Date	Dissolved oxygen (mg/L)
3/18/98	13.24
4/22/98	11.48
5/21/98	9.32
6/24/98	8.45
7/21/98	8.41
8/26/98	8.86
9/16/98	9.53
10/8/98	10.83
11/9/98	12.06
12/14/98	13.52
1/12/99	13.89
2/10/99	13.26
3/16/99	12.8
4/13/99	12.12
5/11/99	11.02
6/17/99	9.3
7/13/99	8.71
8/17/99	8.55
9/22/99	9.79
10/19/99	11.29
11/17/99	13.43
12/13/99	12.83
1/18/00	12.35
2/7/00	12.83
3/13/00	12.33
4/12/00	11.93
5/17/00	11.15
6/14/00	9.85
7/18/00	8.4
8/16/00	8.91
9/20/00	9.89
10/18/00	11.46
11/14/00	13.45
12/13/00	13.66
1/17/01	12.73
2/14/01	13.41
3/14/01	12.86
4/10/01	12.39
5/17/01	10.69
6/19/01	8.96
7/17/01	8.28
8/14/01	8.09
9/18/01	9.84
10/16/01	11.22
11/20/01	12.81
12/18/01	13.79
1/15/02	12.78

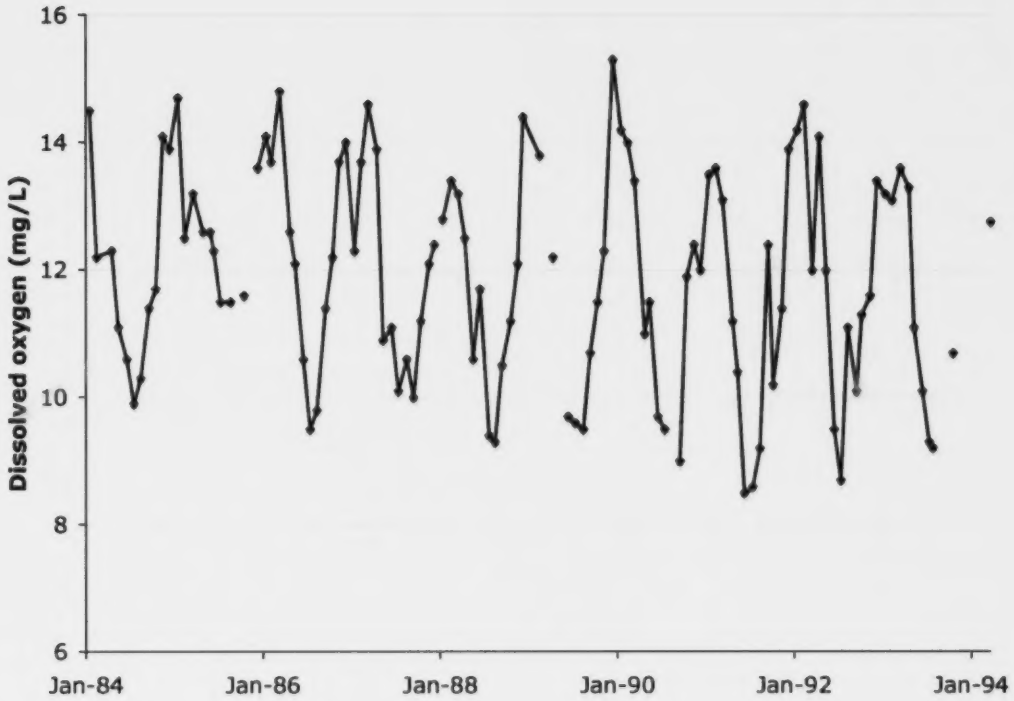
APPENDIX A (ctn'd): Dissolved oxygen concentrations in the Peace River at the Long Term River Network station near Fort Vermillion.

Date	Dissolved oxygen (mg/L)
2/12/02	12.6
3/13/02	12.78
4/15/02	12.7
5/14/02	11.58
6/11/02	9.45
7/15/02	8.62
8/14/02	9.07
9/19/02	9.84
10/16/02	11.32
11/14/02	11.74
12/19/02	12.96
1/16/03	13.99
2/13/03	12.96
3/12/03	13.2
4/8/03	12.46
5/13/03	11.06
6/17/03	9.56
7/15/03	8.68
8/20/03	8.81
9/16/03	8.07
10/22/03	11.82
11/12/03	14.77
12/16/03	14.13
1/13/04	14.02
2/17/04	13.74
3/16/04	13.22
4/14/04	11.06
5/17/04	11.03
6/16/04	9.44
7/15/04	7.88
8/10/04	8.99
9/14/04	10.44
10/20/04	12.17
11/18/04	13.87
12/14/04	13.91
1/11/05	14.06
2/15/05	13.07
3/15/05	5.35
4/14/05	11.39
5/16/05	10.27
6/14/05	9.28
7/18/05	8.74
8/29/05	9.7
9/20/05	10.38
10/19/05	11.49
11/16/05	13.53
12/21/05	14.06

APPENDIX A (ctn'd): Dissolved oxygen concentrations in the Peace River at the Long Term River Network station near Fort Vermillion.

Date	Dissolved oxygen (mg/L)
1/17/06	14.23
2/7/06	13.64
3/14/06	13.45
4/10/06	12.47
5/16/06	10.07
6/13/06	9.24
7/18/06	8.81
8/15/06	8.91
9/18/06	11.61
10/16/06	12.43
11/20/06	15.24
12/19/06	14.11
1/17/07	12.93
2/21/07	13.21
4/19/06	12.75
5/15/06	11.9
6/14/06	9.25
7/18/06	9.45
8/16/06	10.02
9/19/06	12.1
10/18/06	12
11/21/06	13.81
12/19/06	15.05
1/29/07	13.71
2/20/07	13.2
3/12/07	12.87

APPENDIX B: Dissolved oxygen concentrations in the Peace River at the ex-Alberta Environment Long Term River Network station near Dunvegan, 1984 to 1994.



APPENDIX C: Smoky River BOD and associated discharge.

Date	BOD (mg/L)	Discharge (m3/s)
4/22/87	2.3	278
1/29/91	0.7	36
3/20/91	1	56.5
1/26/92	0.5	58
3/11/92	1	142
1/13/93	0.05	34.1
2/9/93	1	33.1
3/10/93	2	45
1/27/94	1	45.5
2/23/94	1.3	35.3
3/24/94	1.2	46.2
1/18/95	1	46.7
2/15/95	1.5	39.1
3/22/95	1	45.3
1/9/96	1.3	51
2/5/96	0.1	36.1
2/28/96	0.4	37.1
1/15/97	1.51	48.1
2/11/97	0.35	47.8
3/12/97	1.5	41.5
10/3/97	2	312
1/20/98	1.4	49
2/18/98	0.6	44.9
3/17/98	1.6	35.4
10/1/98	0.7	115
1/13/99	0.5	45.4
2/18/99	0.05	40.9
3/15/99	0.9	39.1
1/19/00	0.7	28.8
2/8/00	0.9	30.6
3/14/00	0.1	32.8
1/18/01	1.1	45.5
2/15/01	0.6	26.4
3/15/01	0.05	35.5
1/16/02	1.4	42
2/13/02	1.5	34.2
3/14/02	0.8	29.8
1/15/03	1.1	27
2/12/03	1.3	34.1
3/11/03	0.05	31
1/15/04	0.6	39.3
2/18/04	1.8	33.9
3/17/04	2.3	44.6
1/13/05	0.05	76.8
2/16/05	0.7	79.2
3/16/05	3.6	373